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Some Solutions to Technical Hurdles for Developing a Practical Intracortical Visual Prosthesis Device

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Abstract—**The goal of cortical neuroprosthesis researchers of last four decades is to develop a practical intracortical visual prosthesis device. Although the concept of such a system seems straightforward, details of its configuration remain undefined. Knowledge of how the human visual system will respond to artificially-induced visually-based input is sparse. Combined with technological limitations, these have hindered the progress in developing a practical intracortical visual prosthesis device. The long-term objective of this research is to develop a continuously wearable intracortical visual prosthesis device. Earlier studies have used relatively small numbers of cortical electrodes, and these have been insufficient to generate an integrated visual perception. Surgical difficulties also complicate problem. A prototype visual prosthesis system needs to be adaptable to varying stimulation, image processing, and user interface needs. It also has the obvious requirement portability, implying extremely low power consumption and low weight so that the system can be used outside the confinement of a lab. We feel that available technology has sufficiently advanced to develop a first-generation intracortical visual prosthesis device. In this paper we propose some solutions to the challenges for developing this visual prosthesis device using existing technologies.**

Keywords—**Intracortical, visual prosthesis, image processing**

I. INTRODUCTION

Experiments dating back to 1918 have shown generation of visual sensations of small localized spots of perceived light called phosphenes when the visual cortex was stimulated electrically. Experiments in the late sixties and early seventies, on humans, demonstrated that a field of individual phosphenes could be evoked by stimulating the visual cortex with an array of electrodes implanted subdurally over its surface [3][4][5][17][18]. These studies confirmed the visuotopic organization of the visual cortex, and demonstrated that subjects could assimilate information that was delivered to the visual cortex by electrical currents passed via groups of electrodes. This early work provided the path to pursue intracortical visual prostheses approach in which fine wire metal electrodes are inserted into the visual cortex for selective stimulation. It was shown that currents to elicit phosphenes by intracortical microstimulation are ten to hundred times lower than those by non-penetrating electrodes [2][10]. It was suggested that to study the mappings of the brain and do the implants, safe and effective surgical procedures that are cost-effective must be developed and validated in animal models before they are attempted in human volunteers [15] Animal models were used to study the functionality of intracortical visual prostheses and to gain confidence in the implant reliability and safety [1][12][13]. Psychophysical tests to determine the requirements of a cortical prosthesis concluded that with 625 dots (25X25 array) reading and normal walking speed could be achieved [6][7][8].

Even though the fundamental research work needed for an intracortical visual prosthesis has progressed, experimental setups are missing in which the image acquisition is done, processed, and translated into stimulus patterns, to evoke a collection of phosphenes in real time. Long-term safety and biocompatibility of the implants, the integration of implanted electrodes into reliable and interconnected multichannel arrays, fabrication of implantable multichannel stimulators and prostheses that is as unobtrusive as possible continue to be a challenge. Previous experience supports the assumption that high-density electrode implantation over a large part of the visual cortex, can be accomplished, but till now no experiment has been conducted to explore this possibility. A hardware system needed for this proof of concept has to operate in real time i.e., it should capture and process the images in real time and generate the stimulation in real time, if it is to have any sensory benefit to the implanted volunteer. The requirements that will provide long term adaptability of the system have to be defined, and tested, so that the system will be small in size, low in weight and have low power consumption to allow for continuous wearability by the subject. The system should be adaptable to an individual subject's visuotopic mappings and psychophysical behavior. It will have to be flexible enough to be reconfigurable to multiple image processing techniques and long term changes observed in the biological response of individual person. We are using the experience gained from the past experiments and the recent advancements in video-camera and electronic technology, and electrode fabrication, for developing a practical system in which we will try to overcome the technical hurdles.

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II. CHALLENGES AND SOLUTIONS

Essential components of an intracortical stimulation system are: a camera to capture the image, a camera interface with an image processing device, a flexible image processing system, an image processing algorithm, a communication link to the implanted arrays, and large number of implanted electrodes. In addition to these hardware modules, it is necessary to have initial specifications for the parameters for stimulation and the visuotopic mapping of the subject. Each of these components and their requirements provide us with technical challenges to overcome. The hardware requirements of a visual prostheses device have been suggested earlier [11]. We are trying to address the problem of adequate throughput, low power, low weight, flexibility to adapt to different processing algorithms, and user needs within a single system design, that uses currently available technologies.

A block diagram of our proposed first generation visual prosthesis system is shown in figure 1. This system will drive an array of up to 1024 electrodes. Some of the technological challenges and proposed solutions, as well as conceptual questions, are presented below:

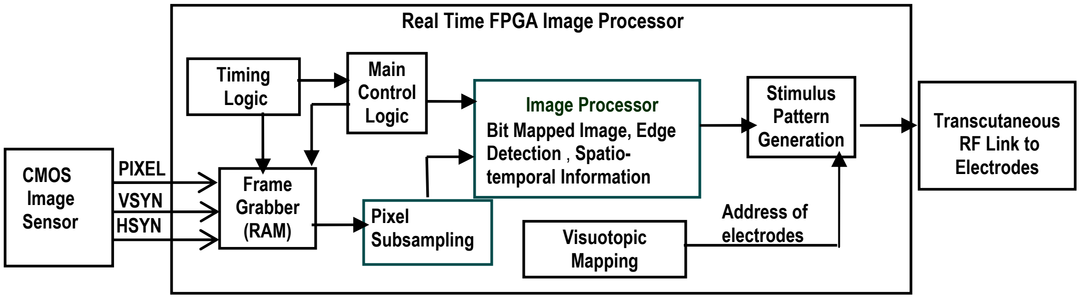

Fig1. A Practical Intracortical Visual Prosthesis Design

What kind of a camera should we select?

The first component of a visual prosthesis to be selected is a camera. The requirement of a camera is that it should be small, it should be small in weight and consume low power with capabilities like auto gain adjust, white balance control with saturation, brightness and hue control so that the camera can be used in different experimental settings. Till some time before cameras which full fill all these requirements were not available. But now with improvement in CMOS imaging technologies cameras fulfilling these requirements are available. We are using Omnivision's OV 7120 camera chip which full fills all this requirements. It is a monochrome CMOS camera which gives digital output. With digital output it is easier to interface it with a DSP or a microprocessor chip running an image processing algorithm. We also considered CCD cameras which have high resolution but they suffer from high power consumption and have no on chip processing capabilities. An extra processing chip increases the power consumption in CCD cameras. Chromatic effects are not observed in subjects who have been blind for long time and no methods are available to elicit the required color phosphenes; hence we will use a monochrome image with 3 to 4 levels of grayscale. Since we will not use color processing and only 3 to 4 levels of grayscale this will also reduce the processing requirements.

What kind of hardware / software should we choose to process the captured images in real time?

Power, size and speed are the factors to be considered to choose hardware or software for implementing the processing algorithms. The biggest challenge of such a system along with power, size and speed is the flexibility of reprogramming. A cortical prosthesis system using surface electrodes to stimulate the visual cortex has been reported [16]. This system used a television camera and belt-worn computer system. This kind of system was heavy and mostly likely uncomfortable for the subject to continuously wear. For image processing, we do not consider a general-purpose PC-based computer system, running image processing algorithm to be practical. Rather, we have chosen to design a hardware/software solution which is dedicated to the specific task of processing for the visual prosthesis application. A longer-term solution is to design an application-specific-integrated circuit (ASIC), but an ASIC would initially be too rigid in terms of adaptability to different processing algorithms. Other solutions might employ a DSP chip or an FPGA. We have chosen to implement the algorithms in an FPGA since it consumes less power than a DSP processor and since processing takes place direct at the hardware level, latencies of calculation are reduced. Pixel-based image processing operations on an image frame are simple and very repetitive and are best implemented in an FPGA with the power consumption being about 20 % of a DSP processor. An FPGA also offers a highly-parallel implementation which reduces latencies of calculations.

The hardware also faces the task of adapting to an individual subject's visuotopic mapping, biological response and long-term adaptability of the cortex. How these may shift once prosthesis is in use is uncertain. Undoubtedly, results from past and ongoing experiments will have to be incorporated in the design. Phosphene onset and extinction reaction time have to be controlled by controlling the on time and off time of each electrode. Maximum and minimum threshold limits to generate phosphenes as well as pulse width and amplitude controls also need to be incorporated.

Based on the above requirements we have selected Xilinx Virtex II Pro FPGA for the image acquisition and processing.

How should we process the images? What kind of an image processing algorithm should we select?

The system by Dobelle (2000), used an edge detection algorithm. Some researchers have also suggested using scene specific image processing [9]. Although perhaps intuitive, many of these suggestions are speculative without any supporting neuroscience experimental data. The nature of processing to be used for the artificial neural interface and the ability to use this interface for invoking non-spatial percepts is unknown. It is often suggested that the plasticity of visual cortex may also be an unknown factor. With all this uncertainty, committing a first-generation system to a volunteer might only be justified by using a more conservative approach. Despite whatever ultimate limitations it may pose, we suggest implementing a bit-map (scoreboard) approach as a first generation system because it is based upon the only experimental evidence of artificial vision available. However, we also feel that it is essential for the system to be rapidly adaptable to algorithms like edge detection and to spatio-temporal manipulation. If the experimental evidence shows that the cortex can adapt to various inputs then even a first generation system needs to be able to select between emerging scene-specific image processing.

What kind of communication link should we use to send stimulation signals to electrodes?

Electrodes could be stimulated using a percutaneous cable entering the skull but there is the fear of inevitable infection. Hence to avoid these problems the commands for the electrodes will be sent on a wireless transcutaneous inductive link to implanted chips that are incorporated directly into 16-electrode arrays. One transmitter coil on the surface of the scalp will be driven by the image processing system to generate the input for the entire implanted wireless system. . The implanted system will consist of a set of discrete IC modules, each with 16 electrodes. Each module contains a chip, controlling stimulation of the 16 electrodes [14]. All modules in this system will receive power and serial commands from the image processing system. The serial command will contain the address of the module with the address of the particular channel to be stimulated. The instruction set will be carrying the information about the amplitude and pulse width of the stimulation pulse to be generated. Since each module is separate and distinct, no interconnecting wires will be required, thus eliminating the transdural conduits associated with connecting cables.

What are the current psychophysical results available that encourages a visual prosthesis device?

To generate a large number of phosphenes a high density of implanted electrodes are required. Cha and colleagues (1992 a,b,c) simulated arrays varying from 100 electrodes (10X 10 array) to 1,024 electrodes(32X32 array), represented by small dots in a video display mounted on ski goggles and a head mounted video camera covered by a perforated mask. They checked visual acuity for tasks like reading and mobility performance. They concluded that with 625 dots a reading speed of 100 words of paragraph text per minute could be achieved and allowed normal walking speed through a maze with obstacles. Visual acuity was found to vary with pixel spacing. They also concluded that head movements are important for vision with simulated arrays since it helped to overcome restricted vision and improved spatial resolution with depth perception. One shortcoming of this experiment is that their testing used identically-sized simulated phosphenes on a regularly-spaced grid which is not a good assumption for estimating the performance of a cortical prosthesis.

In the humans the different visual areas have difficult surgical accessibility with cortical areas located deep within the interhemispheric fissures and calcarine fissures. About two-thirds of the Area 17 lies within a convoluted sulcus. This area corresponds to the lateral visual fields, which is important for navigation. Hence our visual area for intracortical prostheses might be limited to the foveal region unless surgical methods are developed to reach the calcarine fissure laterally. If placed across calcarine fissure the resulted phosphenes will be above and below horizontal meridian [17]. If we observe the earlier maps we don't see lateral phosphenes [3]. If we hypothesize that we will get a similar map with a concentration of phosphenes above and below the horizontal meridian, then we might expect to get an 'hourglass' shaped map of phosphenes. This observation along with different sizes of phosphene observed leads to the conclusion that in a practical cortical prosthesis device the phosphenes will be irregularly sized and spaced [2] [3][17].

An initial phosphene map will be needed for a first-generation prosthesis. Assuming, an hourglass type shape, based upon the surgical placement of the electrodes, we expect to implement a mapping algorithm that allows for irregular phosphene sizes and distributions, but one that can be modified as the mapping information for the user becomes available. The image processing algorithm chosen and the visuotopic mapping incorporated in the device will work as filter masks and the image will be presented as a dotted phosphene image within the hourglass shape. As the image processing system becomes available, prior to use as prosthesis, it will be used for relevant psychophysical tests on normal sighted persons. Normal sighted persons will be presented with what we expect the blind persons to perceive during real time simulation on a virtual reality goggle. The normally sighted person's ability to understand those images will be judged to gain some confidence in the proposed system. The proposed tests are object recognition, mobility and eye-hand coordination test.

V. CONCLUSION

To advance the field of cortical visual prostheses, a system for processing images and presenting the information to the brain via a large collection of electrodes needs to be developed, and that system has to be physically suitable for daily use outside of the laboratory. To access the brain's adaptability to generate a perception from bit mapped phosphenes we need systems which are wearable and can be used outside the confinements of a laboratory. Using currently available technology, it now seems possible to design such a system. As our knowledge of neural coding of visual pathways increases we expect that better techniques and algorithms can be implemented to induce visual perception. A first generation system needs to allow for these changes, and must be designed as such from the onset.

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